

Soils Specialist Report
Forest-Wide Invasive Plant Treatment Project

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1 Overview

Law and Policy Governing the Soil Resource

The need to protect and improve the quality of soil, and avoid permanent impairment of productive capability of NFS lands is governed by multiple laws, summarized below:

- The Organic Administration Act of 1897 was enacted "to improve and protect the forest within the boundaries..."
- The Multiple-Use Sustained-Yield Act of 1960 set forth the secondary purposes of National Forest establishment "for outdoor recreation, range, timber, watershed, and wildlife and fish purposes."
- The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 requires an assessment of the present and potential productivity of the land. This act provides guidelines for land management plans developed to "...insure that timber will be harvested from NFS land only where ... soil, slope, or other watershed conditions will not be irreversibly damaged."
- The National Forest Management Act (NFMA) of 1976 amended the RPA by adding sections that stressed the maintenance of productivity, the need to protect and improve soil and water resources, and avoidance of permanent impairment of the productive capability of the land.

The policies that guide management practices in order to sustain soil quality are found in the national and regional Forest Service Manuals and Handbooks;

National Soil Management Manual (FSM 2550)

The Soil Management Manual (2010) is a national soils handbook that defines soil productivity and components of soil productivity, establishes guidance for measuring soil productivity, and establishes thresholds to assist in forest planning.

Region 5 Soil Management Manual Supplement

The Forest Service Region 5 Soil Management manual Supplement (R5 FSM Supplement 2550-2012-1) establishes guidelines for evaluating and analyzing three soil functions to determine if the national soil quality objectives are being met. The functions address three basic elements for the Soil Resource: (1) Support for Plant Growth Function, (2) soil hydrologic function, and (3) Filtering-Buffering Function.

The thresholds and indicators represent desired conditions for the soil resource. Utilization of the thresholds and indicators provides a consistent method to analyze, describe and report on soil condition

throughout the Region. Desired condition for soils within Riparian Conservation Areas (RCAs) as stated in the Sierra Nevada Forest Plan Amendment (SNFPA) (2004) includes “soils with favorable infiltration characteristics and diverse vegetative cover to absorb and filter precipitation and sustain favorable conditions of stream flow.” Soil function in Riparian Conservation Areas (RCAs) is addressed by standards 103, 111, and 122 in the Sierra Nevada Forest Plan Amendment (USDA Forest Service 2004a).

The INF LRMP includes the following management direction related to soil resources:

- Reduce accelerated erosion resulting from management activities to natural background levels within three years after the soil-disturbing activity. (p. 94)
- Conserve the surface mineral and/or organic layer of the soils by minimizing soil disturbance to maintain long-term soil productivity. (p. 95)

2 Basis for Analysis

This analysis considers two indicators:

Characteristic or attribute being measured or assessed	Indicator	Measure or Unit
Soil productivity/quality	Soil stability/erosion	Management actions (and location) with known erosion issues
	Filtering-Buffering Function of soil	Risk to soil micro-organisms,
		Leaching and off-site movement of herbicides

Analytical conclusions are provided for the indicators. The interactions between soil type and herbicide properties are discussed and relative risks are disclosed. Analytical conclusions about impacts to water quality are found in the hydrology report.

3 Affected Environment

Soils in the project area developed from granitic, metamorphic and volcanic rock. Pumiceous soils with ash are common in the northern parts of the Forest. Glacial and alluvial materials derived primarily from granitic rocks, but with some metamorphic and volcanic rocks (USDA, 1995) are common on the eastern slope of the Sierra Nevada. Soils are generally coarse textured, with most having coarse sand, loamy coarse sand, and sandy loam surface layers. The White and Inyo Mountains are composed of many layers of different sedimentary and metamorphic rocks, with resulting variable soils which are generally shallow (USDA, 1993). Slope steepness ranges from 0-75%. The Kern Plateau also has mostly granitic parent material with scattered pre-batholith parent material and volcanics, but soils differ from more northern portions of the Sierra because this area was not glaciated in the recent glaciations (USDA, 1996).

3.1 General Soil Conditions

There are relatively few areas on the Forest with widespread accelerated erosion beyond the natural range of variability. Erosion rates far outside of the natural range of variability have been observed mainly along roads, developed areas (such as ski areas), in streams in areas of concentrated grazing, and after wildfires of moderate or high intensity. Many erosion issues can be addressed through mitigations or restoration activities, or through project design with the installation of appropriate drainage and erosion control techniques.

4 Environmental Consequences

4.1 Alternative 1 - Proposed Action

4.1.1 Direct and Indirect Effects

This analysis describes potential effects of manual, chemical, cultural and biological control on infested acres, over a 10-year period. These effects would be present on the currently known 58 acres of infestations with the goal of eradication and 1431 acres of infestations the Forest wants to control focusing on reducing the acreage and percent cover over time and new and expanded infestations. Chemical treatments would be used on infestations found to be ineffective to treat by manual and cultural methods.

Erosion potential due to soil disturbance would be controlled through the design feature that specifies evaluation of disturbed, bare areas greater than 0.1 acre, with subsequent erosion control measures prescribed as needed (DF #33).

Manual Treatments

The overall impacts of manual pulling, cutting, and clipping are very low. Mowing would use low ground pressure equipment to minimize rutting and soil disturbance. Some of these activities would temporarily decrease ground cover in patches but potential erosion hazard from such small areas would be low, possibly causing some very localized erosion, on the order of a few square feet per occurrence. If the cut material were left on site, minor short-term benefits from additional soil cover and organic matter addition would be provided. Monitoring of ground disturbing activities would occur to ensure compliance with BMPs. Impacts to soils from manual and mechanical treatments would be minor under current and expected future infestation levels. Risk of soil loss from erosion would be controlled by the design feature that prescribes evaluation and potential erosion control treatment.

Cultural Treatments

Cultural methods include tarping (solarization), seeding, and thermal methods involving flame, steam, or infrared application. These methods generally do minimal disturbance to the soil surface. Thermal methods are applied to individual plants causing a temporary, spotty reduction in soil cover and would not appreciably increase the risk of soil erosion.

Areas may be seeded following treatment, which would facilitate rapid recovery of vegetative soil cover.

Thermal treatments would not increase soil temperatures enough to impact soils or soil biota (microorganisms and soil invertebrates).

Biocontrol

No ground disturbance would occur with this treatment therefore no effects to soil or water resources are expected.

Chemical Treatments

The magnitude of potential effects from chemical treatments would vary with the specific chemical and the amount of chemical applied. The amount of chemical applied would be dependent on the size of the infestation and the method of application; hand/selective application methods would deliver the least amount of chemical to the soil, followed by directed spray, with limited broadcast spray delivering the greatest amount of chemical to the soil, of these application methods.

The soils section describes the soil properties related to potential water quality impacts and the interactions between soil type and the proposed herbicides. However, the amount of chemical applied is often the most important factor in determining the potential for water quality impacts. This factor is discussed in the hydrology section.

Below is a brief summary for each chemical proposed for use detailing each chemical's behavior in soils, including persistence, leaching potential, soil micro-organisms (biota) and movement offsite.

Aminopyralid: Aminopyralid has been shown to be practically non-toxic to most soil organisms (SERA 2007). It has an average half-life of 35 days and can be considered highly mobile in most permeable soils (DiTomaso et al. 2013). Even with its low toxicity, the high mobility leachability of aminopyralid warrants special consideration in zones of high water table. Because of this leachability there is a project design criteria that address the application of aminopyralid on low permeability and/or saturated soils (DF #36). The low application rates, the method of application, and the design criteria outlined for this project would prevent unacceptable leaching of aminopyralid.

Chlorsulfuron: This herbicide has an average soil half-life of 28-42 days. This herbicide has low mobility as it readily adsorbs to soil. This project proposes to only spray chlorsulfuron directly onto plant surfaces, or wick and wipe it on, rather than broadcast spray or incorporate into the soil. There is no basis for asserting that chlorsulfuron is likely to cause adverse effects in soil microorganisms under the conditions of application covered in the risk assessment (SERA, 2004).

Clethodim: This herbicide has a half-life in the soil of 3 days with very low mobility and rapid degradation. The toxicity of clethodim to terrestrial microorganisms is not addressed in the available literature. Consequently, no dose-response assessment can be proposed for soil microorganisms. (SERA, 2014).

Clopyralid: This herbicide has a soil half-life of 12-70 days with an average of 40 days and moderate mobility. Even with its low toxicity the high mobility leachability of clopyralid warrants special consideration in zones of high water table. Because of this leachability there is a project design criteria that addresses the application of Clopyralid on deep, coarse textured, saturated soils (DF # 36). The estimated maximum soil concentrations are far below potentially toxic levels to soil organisms (SERA, 2004). The low application rates, the method of application, and the design criteria outlined for this project would prevent unacceptable leaching of Clopyralid.

Fluazifop-P-butyl: This herbicide binds strongly with soils, is not highly mobile, and has low persistence, with an average half-life of 15 days (DiTomaso et al. 2013). Though data is minimal at this time, fluazifop-p-butyl does not appear to impact most soil organisms when applied at the proper rate (SERA 2014a).

Glyphosate: Glyphosate rapidly and tightly binds to soil. There is little potential for leaching or offsite movement due to its very strong adsorption to soil. Similarly, glyphosate has a low risk of impacting soil microorganisms (SERA 2011). Glyphosate becomes inactive as an herbicide upon contact with the soil. Glyphosate is degraded via microbial activity and has a half-life of 47 days (DiTomaso et al. 2013).

Imazapyr: Soil half-life for imazapyr is 25-142 days depending on soil type. Sources document variable mobility and leaching of imazapyr, in soils probably because the binding of imazapyr to soil is completely dependent upon a variety of soil properties (HFQLG Final Supplement EIS 2003). It can be mobile, especially in high pH environments present on much of the Forest. SERA (1999: App. 5-2) noted that binding of soil to imazapyr increases with increasing pH, increasing iron oxide levels and elevated organic matter at lower pHs. It is susceptible to surface runoff, and leaching from dead roots. This project proposes to only spray imazapyr directly onto plant surfaces, or wick and wipe it on rather than broadcast spray or incorporate into the soil. Because of this leachability there is a project design criteria that address the application of imazapyr on deep, coarse textured, saturated soils (DF #36). The estimated maximum soil concentrations are far below any potentially toxic levels to soil organisms. Thus, there does not appear to be any basis for asserting that imazapyr is likely to affect soil microorganisms adversely (SERA, 2011).

Triclopyr: The soil half-life of triclopyr is 10-46 days with an average of 30 days. It is generally not considered to have potential for ground or surface water contamination, though, is occasionally found in surface water at low concentrations when broadcast sprayed (see Hydrology Specialist report). Given the potential for runoff into surface water, no broadcast spraying is proposed for this project. The potential for substantial effects on soil microorganisms appears to be low. Only laboratory studies on the effects of triclopyr on soil microorganisms are available. Based on these, the growth of some bacteria or fungi might be inhibited as a transient effect, but this effect would not likely be large enough to shift the population structure of microbial soil communities such that the capacity of soil to support vegetation would be impacted (SERA, 2016).

Overall, the proposed herbicide types and application rates are expected to facilitate decay by soil microbes. Risk to soil microorganisms is low. Where plants are killed, the residue would continue to

provide some soil cover until new plants establish. The treatment areas are generally small and discontinuous, reducing the possibility of transport via wind or water erosion. The potential for adverse effects of herbicide residues in soil would be minimized or eliminated by incorporating the project design features and applying BMPs for herbicide application.

At least 58 acres are expected to receive multiple applications of herbicide over the course of several years to eradicate the highest priority species such as knapweeds and perennial pepperweed. All the proposed herbicides have a soil half-life less than 142 days (DiTomaso, et al. 2013). Due to degradation and by following the label application rates, cumulative accumulation of herbicide in the soil is not expected.

Indirect effects resulting from herbicide application to soil can be offsite transport of the herbicide attached to soil particles via wind or water erosion. Also, movement of the herbicide down through the soil profile can result in groundwater contamination. In general, primary herbicide processes in soil are leaching, hydrolysis, and adsorption/desorption onto soil particles, and biological degradation. Rapidly drained soils have greater propensity to transfer herbicides to groundwater. However, the herbicides to be broadcast sprayed in this project will be applied at low enough rates and using label directions, so that groundwater contamination will not occur. Organic rich soils and finer texture soils have higher adsorption potential for holding herbicides. Herbicides would vary in the degradation rates based on their chemical structure and site-specific soil characteristics. All of the herbicide application planned in the project is either directed spray, select methods (hack and squirt, wick, wipe and drizzle), or broadcast spray. No chemicals would be aurally (helicopter/airplane) sprayed.

Some chemical would land on the soil surface where it could be transported off site via wind or water erosion. Wind erosion is a major transport mechanism for soil (e.g., Winegardner 1996), especially in some areas on the East Slope of the Sierra Nevada. This mechanism has been associated with the environmental transport of herbicides (Buser 1990). Numerous models have been developed for wind erosion (e.g., Strek and Spaan 1997; Strek and Stein 1997) and the quantitative aspects of soil erosion by wind are extremely complex and site specific. The temporal sequence of soil loss (i.e., the amount lost after a specific storm event involving high winds) depends heavily on soil characteristics as well as meteorological and topographical conditions. While potential damage to non-target areas due to the erosion of contaminated soil by wind cannot be totally dismissed, the risks associated with this scenario are far below those of other exposure scenarios for non-target areas considered in the risk assessments (i.e., drift, and runoff). Factors controlling these processes include: amount of soil cover, degradation rate of chemical when exposed to sun and air, soil infiltration rate, soil texture, slope, and weather events such as wind and rain following application. Due to the patchy, discontinuous nature of directed spray and select application methods, soil cover would largely remain intact with a combination of live and dead plants.

Broadcast application of Aminopyralid, Clethodim, Clopyralid, Fluazifop and Glyphosate could occur. The risk of offsite movement is highest with Aminopyralid and Clopyralid given their longer soil half-life (as compared to the other chemicals proposed) and leaching potential. Broadcast spraying could occur adjacent to roads which are compacted surfaces and can transport runoff water entrained with

herbicide. The risk of offsite movement is low due to residual soil cover with directed spray and select application, design features that preclude spraying when storms are approaching, high infiltration rates, and high density of weeds to provide interception and soil cover and potential reseeding for rapid vegetative recovery where broadcast spraying takes place.

Degradation and Environmental Characteristics

As discussed, there are several degradation pathways an herbicide may degrade through. Microbial degradation of the proposed herbicides is reliant on the combination of climate, soil, and herbicide characteristics. Soil moisture increases microbial activity and the rate of degradation of some herbicides, such as glyphosate and fluazifop-p-butyl.

Climate across the Forest is generally warm, dry summers and cool, wet winters. It is expected that microbial activity will be highest in spring when there are increases in soil moisture and temperature. Dry years or periods of extended drought would be expected to have slower degradation rates as microbial activity would be limited.

Adsorption of herbicides to soils can slow the degradation process and lead to persistence in the soil. Soils that are coarser grained and have lower organic matter percentages are less likely to retain herbicides through adsorption. The majority of soils in the analysis areas tend to be coarser grained, so herbicides that form weaker bonds are less likely to adsorb and may be more readily metabolized by microbes. The length of time it takes an herbicide to degrade is also relevant to the potential for water quality impacts when the herbicide comes in contact with soil. Degradation is generally expressed as half-life – the length of time it takes for a chemical to degrade to one-half the original activity level. Herbicides may be classified by half-life as

- Non-persistent (half-life less than 30 days).
- Moderately persistent (half-life of 30-100 days).
- Persistent (half-life greater than 100 days) (Mahler et al. 2002).

Based on these categories, Clethodim, Fluazifop, Glyphosate would be considered non-persistent, and Aminopyralid, Clopyralid, Triclopyr and Chlorsulfuron would be considered moderately persistent. Imazapyr would be considered moderately persistent to persistent.

The half-life of a given herbicide varies with soil texture and moisture. The soils in the analysis area tend to be well-drained to excessively-drained. Although some herbicides degrade faster with higher soil moisture, the somewhat excessively drained and excessively drained soils transmit water quickly and as a result may have lower microbial activity, especially during warm, dry summers or periods of drought. The well-drained soils retain moisture longer and are expected to have higher microbial activity.

Coarse textured soils with aerobic (non-saturated) soil moisture conditions yield shorter half-lives than fine-textured soils under saturated conditions. Thus, for summer and fall applications half-lives would tend to be more toward the shorter end of the ranges given for a specific chemical.

The proposed chemicals are non-persistent to moderately persistent (except for Imazapyr) in soil, which limits the risk to water quality. Overall, although the climate and soil conditions may reduce microbial

degradation rates, the dry climate and sporadic precipitation will limit potential for transport events before at least partial degradation of the herbicide. BMPs, design features and label instructions will further reduce risks.

Mobility and Environmental Factors

Mobility of a given herbicide is reliant on the combination of climate, herbicide, and soil characteristics. The solubility and adsorption potential of the herbicide can affect risk of herbicide transport. However, the soil characteristics such as permeability and runoff can contribute to transport of herbicides to groundwater and/or surface waters. Climate can determine the likelihood of storm events and precipitation available to transport herbicides. The herbicides that have the highest potential for transport include imazapyr, triclopyr, aminopyralid and clopyralid. Fluazifop-p-butyl, glyphosate, clethodim, and chlorsulfuron tend to adsorb strongly to soils.

Most of the soils in the analysis area have moderate to very rapid permeability which indicates that water moves quickly through the soil.

The herbicides that have the highest potential for transport through runoff and leaching because of solubility or adsorption characteristics include imazapyr, triclopyr, aminopyralid and clopyralid. Should these herbicides be transported it is important to note degradation pathways and rates. For example, although triclopyr has potential to be transported off site because it is soluble and does not strongly bond to soils, triclopyr breaks down readily in both groundwater and surface water. Should aminopyralid, clopyralid or imazapyr be transported through runoff, sunlight breaks both down readily. Breakdown of aminopyralid and clopyralid without sunlight is much slower and imazapyr needs sunlight to be broken down at all. Leaching potential should be low as herbicide applications will mostly occur during the dry season when there will be a lack of a wetting front to percolate the herbicides downward during the initial half-life.

Fluazifop-p-butyl, glyphosate and clethodim could be transported off site via transport of sediments that the herbicide has adsorbed to. In general, less steep areas have lower risks of erosion. The highest concentration of invasive species tend to be in riparian and floodplain areas as well as roads, parking lots and facilities, that are flatter than surrounding terrain but can be susceptible to flooding and transport.

Soil Properties Related to Water Quality Risk

Herbicides can reach surface or ground water by three major routes: drift from spray, leaching through soil to groundwater, and surface runoff to surface waters. Drift is addressed in the hydrology section; leaching and runoff potential are discussed here.

It is important to note that the ratings for leaching and runoff potential represent only relative risk among different soil types. The actual risk to water quality depends not only on the soil type, but also on the interactions between soil type and the specific chemical, and most importantly, the amount of chemical applied. Thus a soil with a high leaching potential and a high runoff potential would have the

greatest potential for water quality impacts as compared to a soil with a low leaching potential and low surface runoff rating. However, if a very small amount of chemical is applied, the risk to water quality may be negligible on either soil type.

It is also important to note that only a small part of the herbicide applied would have the potential to impact water quality: herbicides are taken up by plants and degraded by microorganisms in the soil, and broken down through a variety of chemical processes.

Leaching potential is dependent on depth to water table, the rate at which water moves through the soil, and the soil's ability to bind (adsorb) pesticides.

Surface runoff is dependent on slope and the ability of the soil to accept and transmit water. Data from the soil surveys (USDA, 1993 and 1995) were used to determine surface runoff potential.

Some of the infestations that need to be treated with chemicals occur in soils with high runoff characteristics. Soil within the Riparian Conservation Area (RCA) adjacent to live water have high leaching potential primarily due to their relatively shallow water tables. Design features to lower the risk of water quality impacts on these soils consist of buffers, avoiding chemical application when precipitation is imminent, and prescribing application methods that use the smallest possible amounts of herbicide, such as cut-stump treatment.

4.1.2 Cumulative Effects

This analysis addresses effects to soils that occur directly on site or adjacent to treatment sites. Cumulative Effects are considered for a 10 year horizon. This timeframe generally encompasses the life of the project and time it can take for expected vegetative recovery.

The impacts to soils from manual and mechanical and cultural control methods would be negligible, and would not be additive to planned disturbances from fuels treatments, residential and roadway construction activities, and recreation activities.

Low application rates and application methods that target individual plants would limit herbicide contact with soils and ensure that soil organisms would be minimally impacted by chemical treatments. The proposed herbicides are non-persistent to moderately persistent (except for Imazapyr) and these chemicals would not build up in the soil and would be unlikely to affect water quality, when applied as directed on the label and with the design features specified herein.

Cumulative effects to soils from proposed manual, mechanical, and chemical treatments would be negligible under current and expected future infestation levels.

4.2 Alternative 2 – No Action

4.2.1 Direct and Indirect Effects

Current treatment options are limited to known infestations as of 2007. Manual methods include: hand pulling, pulling using tools, clipping, mulching, and tarping. Chemical methods include: wiping, and clipping and dipping. The impacts from these treatments are disclosed in the 2007 Forest Weed EA.

The current methods have not proved adequate to eradicate or control the spread of known invasive plants and do not allow for treatment of new infestations. The No Action alternative would result in continued spread of weeds on the Forest, with accompanying impacts to soils.

Weeds can change soil biology (microbial communities and other soil organisms) as well as soil nutrient and carbon status, usually with negative effects to native plant communities. For example, both spotted and diffuse knapweed release chemicals into soil that suppress soil microbes and native plant growth (Vivanco et al 2004). There is evidence that cheatgrass may alter soil microbial community composition, decreasing mycorrhizae that some native plants depend on for optimal nutrient uptake and growth, improved water relations and other benefits (Belnap & Philips 2001).

Invasive species can destabilize native plant communities through their impacts on nitrogen dynamics, changing N availability by changing litter quantity and quality, rates of N²-fixation, or rates of N loss (Evans et al 2001). Changes in nitrogen dynamics may also change soil pH (Ehrenfield et al 2001).

Cheatgrass may alter nitrogen availability to its advantage and the detriment of native plants (Rowe et al 2008). Soil organisms that decompose organic matter have demonstrated preferences for particular substrates, so altering the soil organism community may affect below-ground carbon storage (Ekschmitt et al 2008). Since soil structure is partially dependent on soil biology, disrupting the soil biological community may eventually result in changes to soil structure (Young et al 1998). Given the known impacts of some species of weeds, impacts to some soil organisms could be greater under No Action if infestations continue to increase.

References:

- Belnap, J. and S.L. Philips. 2001. Soil biota in an ungrazed grassland: response to annual grass (*Bromus tectorum*) invasion. *Ecological Applications* 11 (5): 1261-1275.
- Bakke, D. 2000. A Review and Assessment of the Results of Water Monitoring for Herbicide Residues For the Years 1991 to 1999. Unpublished Internal Forest Service Report. Region 5, Vallejo, CA. 38p.
- Bakke, D. 2001. Unpublished. A Review and Assessment of the Results of Water Monitoring for Herbicide Residues for the Years 1991 to 1999, USFS Region Five.
- Berg, Neil. 2004. Assessment of Herbicide Best Management Practices: Status of Our Knowledge of BMP Effectiveness. Pacific Southwest Research Station. USDA FS, Albany, CA.
<http://www.fs.fed.us/r6/invasiveplant-eis/Region-6-Inv-Plant-Toolbox/#link05>
- Buser HR. 1990. Atrazine and other s-triazine herbicides in lakes and in rain in Switzerland. *Environ. Sci. Technol.* 24(7): 1049-1058.
- DiTomaso, J. M.; Kyser, G. B.; Oneto, S. R.; Wilson, R. G.; Orloff, S. B.; Anderson, L. W.; Wright, S. D.; Roncoroni, J. A.; Miller, T. L.; Prather, T. S.; Ransom, C.; Beck, K. G.; Duncan, C.; Wilson, K. A.; Mann, J. J., 2013. Weed control in natural areas in the Western United States. Weed Research and Information Center, University of California, 544 pp
- Ehrenfield, J.G., Kourtev, P., and W. Huang. 2001. Changes in soil functions following invasions of exotic understory plants in deciduous forests. *Ecological Applications* 11(5): 1287-1300
- Ekschmitt, E.K., Kandeler, E., Poll, C., Brune, A., Buscot, F., Friedrich, M., Gleixner, G., Hartmann, A., Kästner, M., Marhan, M., Miltner, A., Scheu, S., and V. Wolters. 2008. Soil-carbon preservation through habitat constraints and biological limitations on decomposer activity. *J. Plant Nutr. Soil Sci.* 2008, 171, 27–35
- Evans, R. D., Rimer, R., Sperry, L., and J. Belnap. 2001. Exotic plant invasion alters nitrogen dynamics in an arid grassland. *Ecological applications*, 11(5), 2001, pp. 1301–1310
- Frazier, JW., S.L. Grant 2003. Water Quality Monitoring for Herbicide Residue, Stanislaus National Forest, 1995-2002. Unpublished Report on File at USDA Forest Service, 2545 Greenley Dr. Sonoma, CA. June 2003.
- LRWQCB. 1995. Water Quality Control Plan for the Lahontan Region. State of California Regional Water Quality Control Board, Lahontan Region.
- Norton, J.B., T.A. Monaco, J.M. Norton, D.A. Johnson, and T. A. Jones. 2004. Soil morphology and organic matter dynamics under cheatgrass and sagebush-steppe plant communities. *Journal of Arid Environments* 57:445-466.

- Rowe, H.I., Brown, C.S., and M. W. Paschke. 2008. The Influence of Soil Inoculum and Nitrogen Availability on Restoration of High-Elevation Steppe Communities Invaded by *Bromus tectorum* Restoration Ecology Vol. 17, No. 5, pp. 686–694
- SERA (Syracuse Environmental Research Associates, Inc.) 2014: Scoping/Screening Level Risk Assessment on Clethodim: Final Report. October 30, 2014 SERA TR-056-08-02b. Manlius, New York 246 pp.
- SERA (Syracuse Environmental Research Associates, Inc.) 2014: Scoping/Screening Level Risk Assessment on Fluazifop-P-Butyl: Final Report. July 21, 2014 SERA TR-056-07-02a, Manlius, New York 293 pp.
- SERA (Syracuse Environmental Research Associates, Inc.) 2007b. Aminopyralid (Milestone) – Human Health and Ecological Risk Assessment Final Report. June 28, 2007. SERA TR-052-04-04a. Fayetteville, New York. 231 pp.
- SERA (Syracuse Environmental Research Associates, Inc.) 2011. Imazapyr - Human Health and Ecological assessment – Final Report. December 16, 2011. SERA TR 052-29-03a, Manlius, New York. 196 pp
- SERA (Syracuse Environmental Research Associates, Inc.) 2004a. Chlorsulfuron - Human Health and Ecological Risk Assessment – Final Report. November 21, 2004. SERA TR 04-43-18-01c. Fayetteville, New York. 180 pp.
- SERA (Syracuse Environmental Research Associates, Inc.) 2011a. Glyphosate – Human Health and Ecological Risk Assessment – Final Report. March 25, 2011. SERA TR 052-22-03b. Fayetteville, New York. 313 pp
- SERA (Syracuse Environmental Research Associates, Inc.) 2011b. Triclopyr – Human Health and Ecological Risk Assessment – Final Report. May 24, 2011. SERA TR 052-25-03a. Fayetteville, New York. 251 pp
- SERA. (Syracuse Environmental Research Associates, Inc.) 2004b. Clopyralid—Human health and —final report. Dec. 5, 2004, TR 04-43-17-03c Fayetteville, New York 154 pp.
- SERA. (Syracuse Environmental Research Associates) 1999. *Imazapyr (Arsenal, Chopper, and Stalker Formulations)* Final Report. February 26, 1999. TR 98-21-14-01b. Fayetteville, New York, 205pp.
- Strek G; Spaan WP. 1997. Wind erosion control with crop residues in the Sahel. Soil Sci Soc Am J. 61(3): 911-917.
- Strek G; Stein A. 1997. Mapping wind-blown mass transport by modeling variability in space and time. Soil Sci Soc Am J. 61(1): 232-239.
- Vivanco, J.M., Bais, H.P., Stermitz, F.R., Thelen, G.C., and R. M. Callaway. 2004. Biogeographical variation in community response to root allelochemistry: novel weapons and exotic invasion. Ecology Letters, (2004) 7: 285–292

- USDA Forest Service. 1988. Inyo National Forest Land and Resource Management Plan. USDA Forest Service, Bishop, CA.
- USDA Forest Service, 1994. Soil Survey: East Part, Inyo National Forest Area California. Pacific Southwest Region. September 1994.
- USDA Forest Service 1995. Soil Survey: Inyo National Forest West Area California. Pacific Southwest Region. June 1995.
- USDA Forest Service 1996. Soil Survey: Sequoia National Forest California. Pacific Southwest Region. June 1996.
- USDA Forest Service 2003. Herger Feinstein Quincy Library Group Forest Recovery Act Supplemental Final Environmental Impact Statement Pacific Southwest Region, Lassen, Plumas, Tahoe National Forests. August 2003.
- USDA Forest Service 2004. Sierra Nevada Forest Plan Amendment Final Supplemental Environmental Impact Statement – Record of Decision, U.S.D.A. Forest Service, Pacific Southwest Region, R5-MB-046, Vallejo, CA. 55 pages plus various appendices.
- Winegardner DL. 1996. An Introduction to Soils for Environmental Professionals. CRC Press, Boca Raton, Florida. 270 pp.
- Young, I.A., Blanchart, E., Chenu, C., Dangerfield, M., Fragoso, C., Grimaldi, M., Ingram, J., and L.J. Monrozier. 1998. The interaction of soil biota and soil structure under global change. *Global Change Biology* (1998) 4, 703–712.